GEOTECHNICAL ENGINEERING

ENGR. DARIO A. CALAQUE, JR.

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LET'S REVIEW

SOIL PROPERTIES

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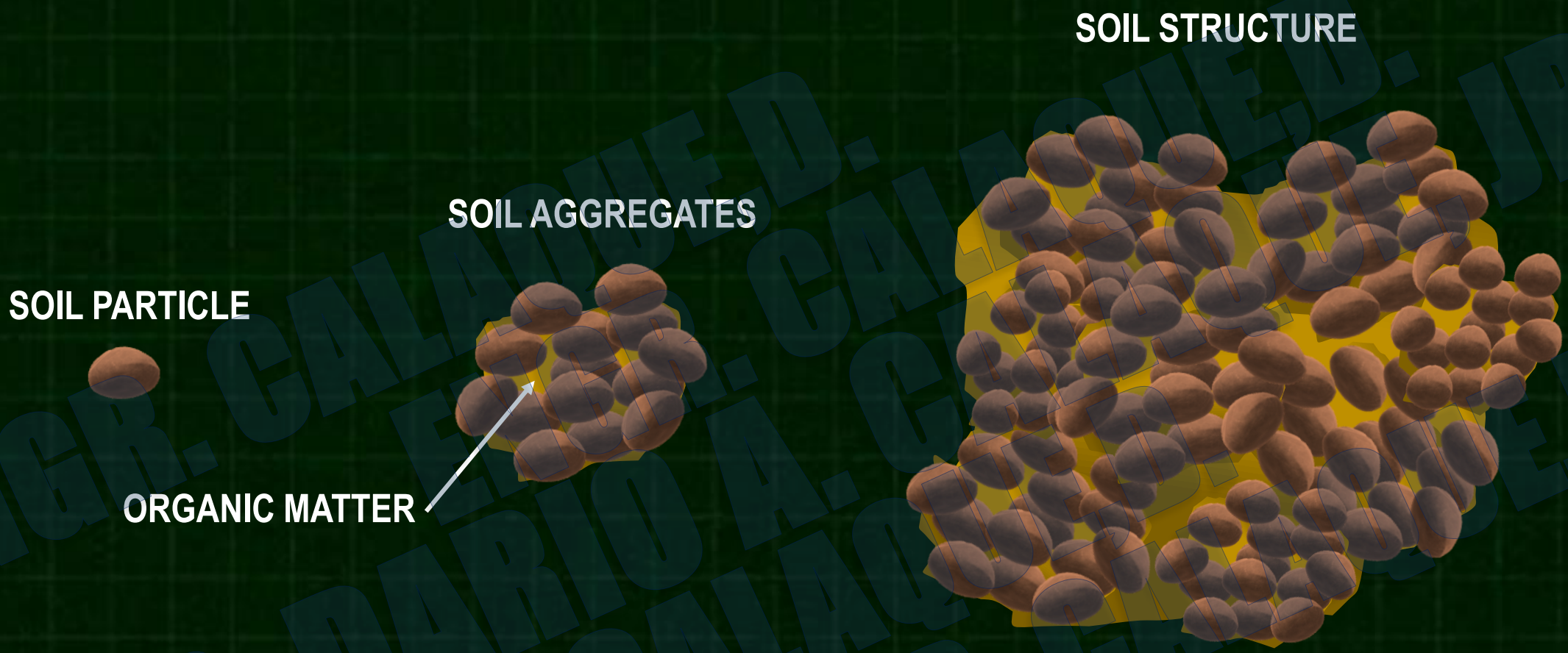

Soil structure refers to the arrangement and organization of soil separates or individual soil particles into units called soil aggregates. The arrangement of soil aggregates gives soil its structure.

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SOIL STRUCTURE

SOIL AGGREGATES

SOIL PARTICLE

Soil structure can therefore be short term, TEMPORARY PROPERTY of the soil, whereas soil texture is PERMANENT.

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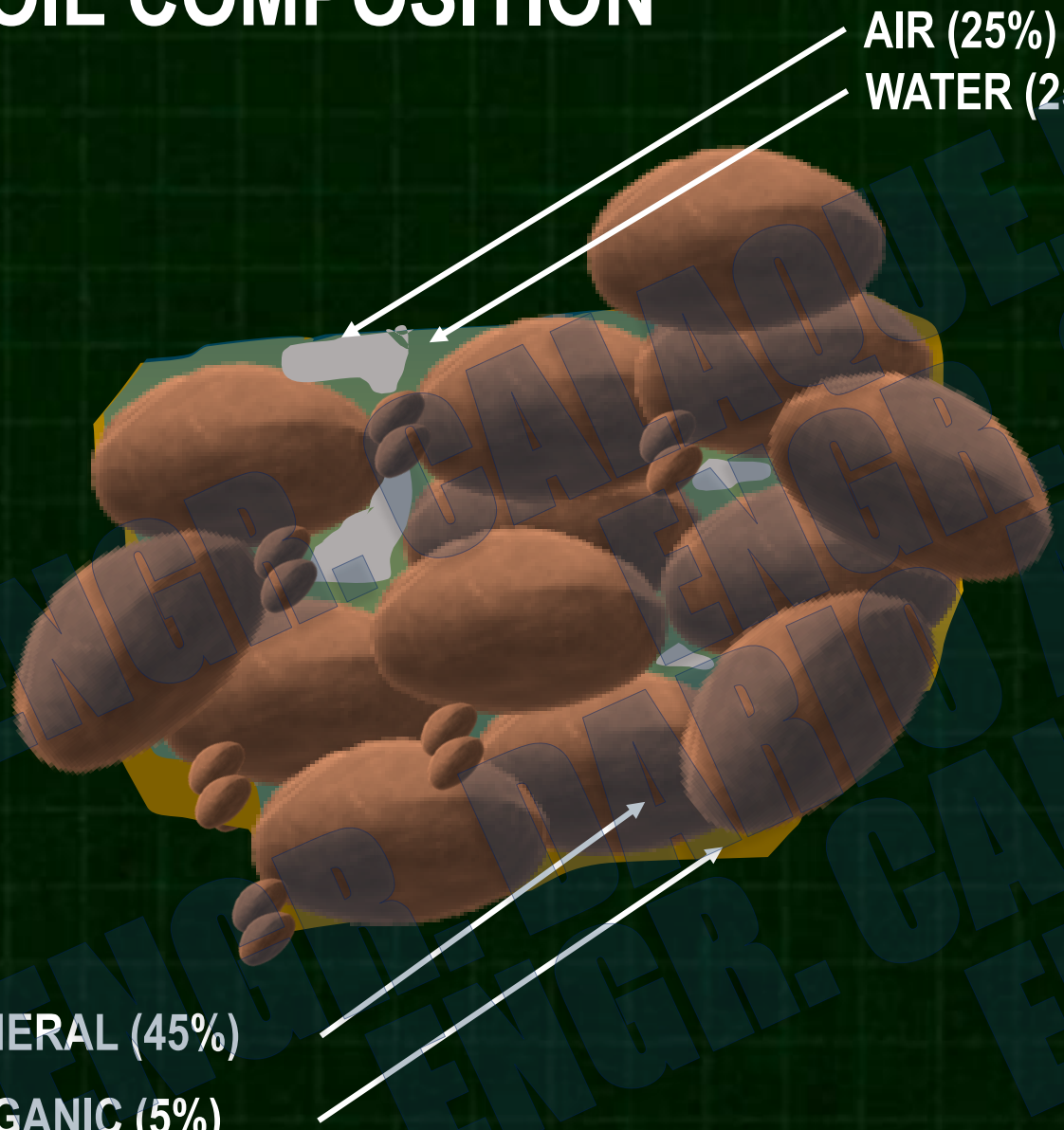
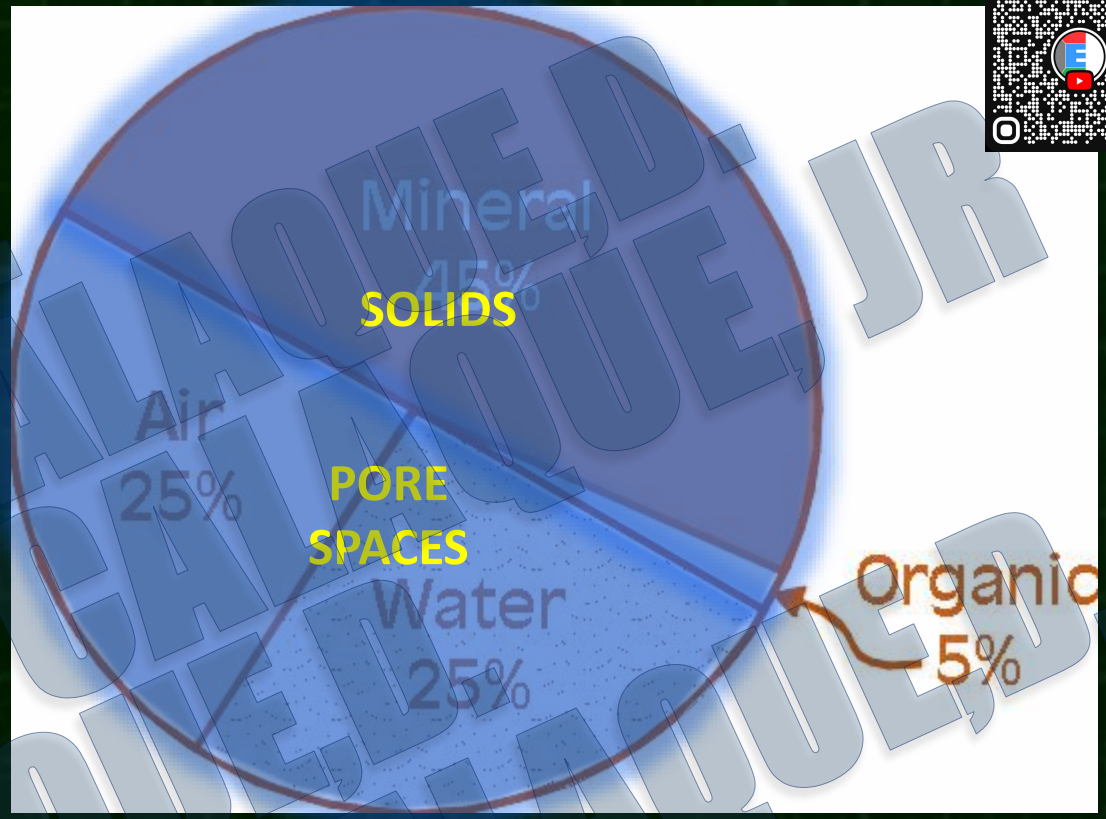
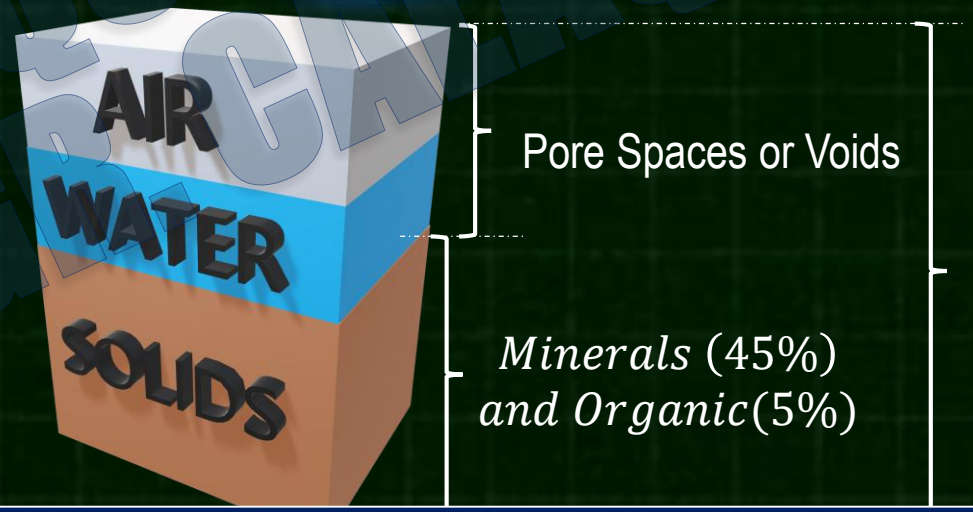
SOIL COMPOSITION







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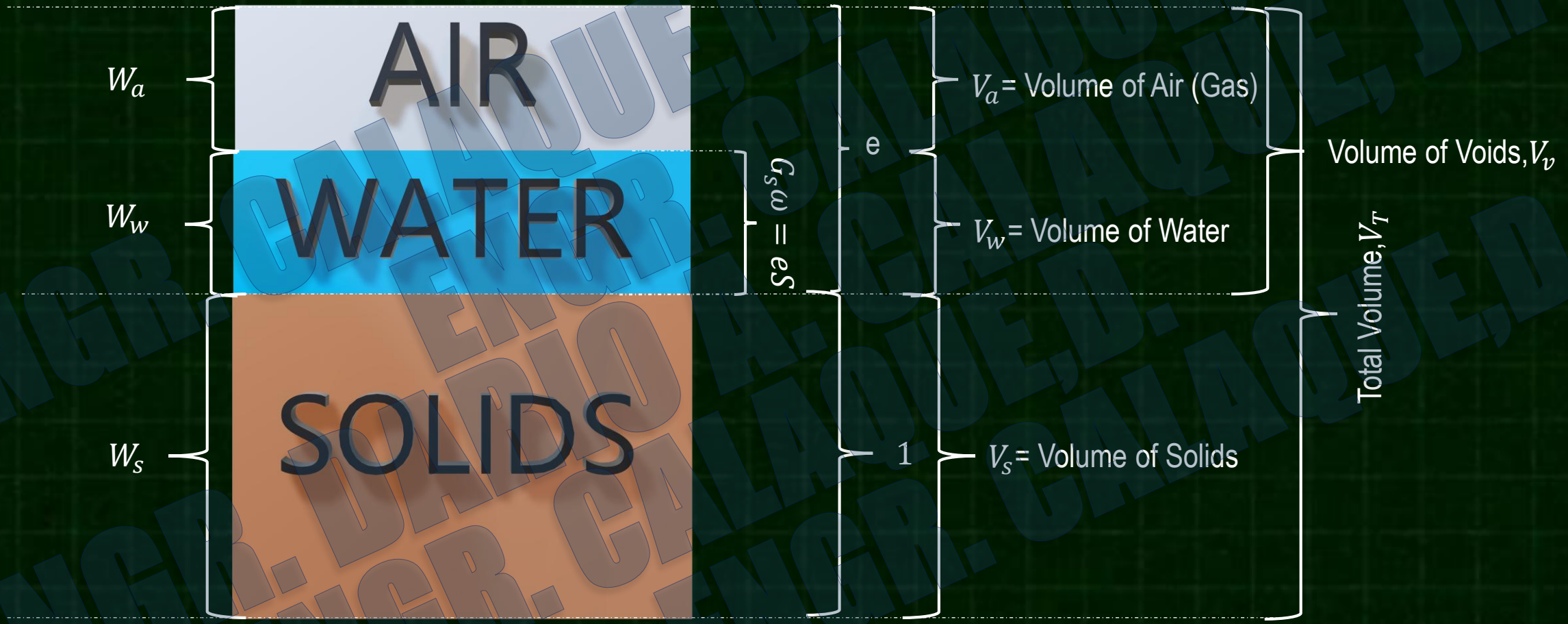

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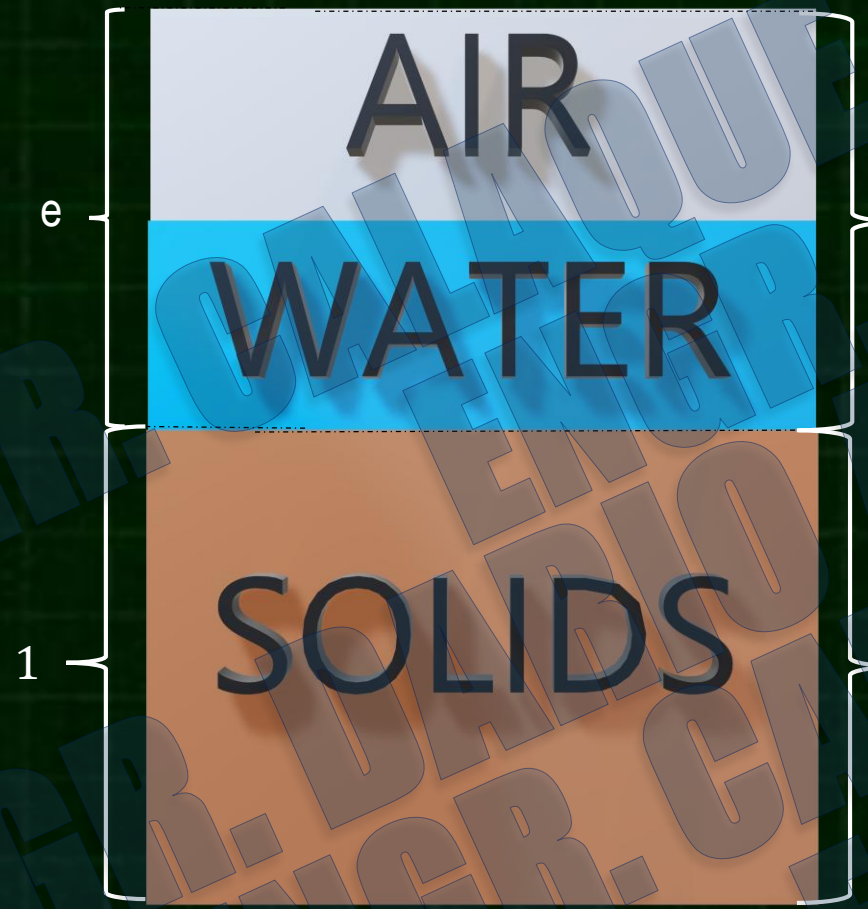

Volume of Voids, V_v

$\frac{e}{1} = \frac{V_v}{V_s}$

V_s = Volume of Solids

Void Ratio

$$e = \frac{V_v}{V_s}$$

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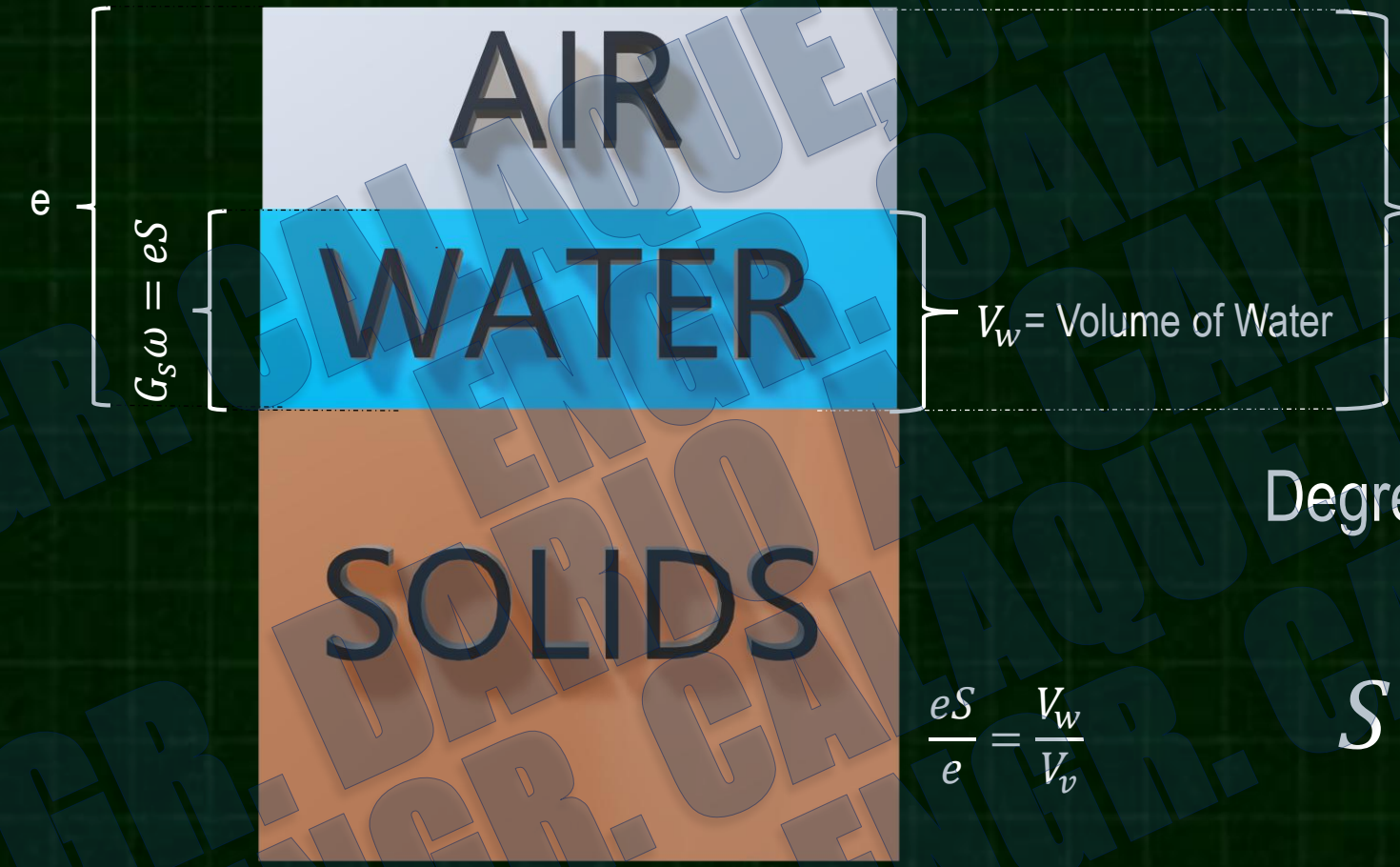

$$\frac{eS}{e} = \frac{V_w}{V_v}$$

Degree of Saturation

$$S = \frac{V_w}{V_v}$$

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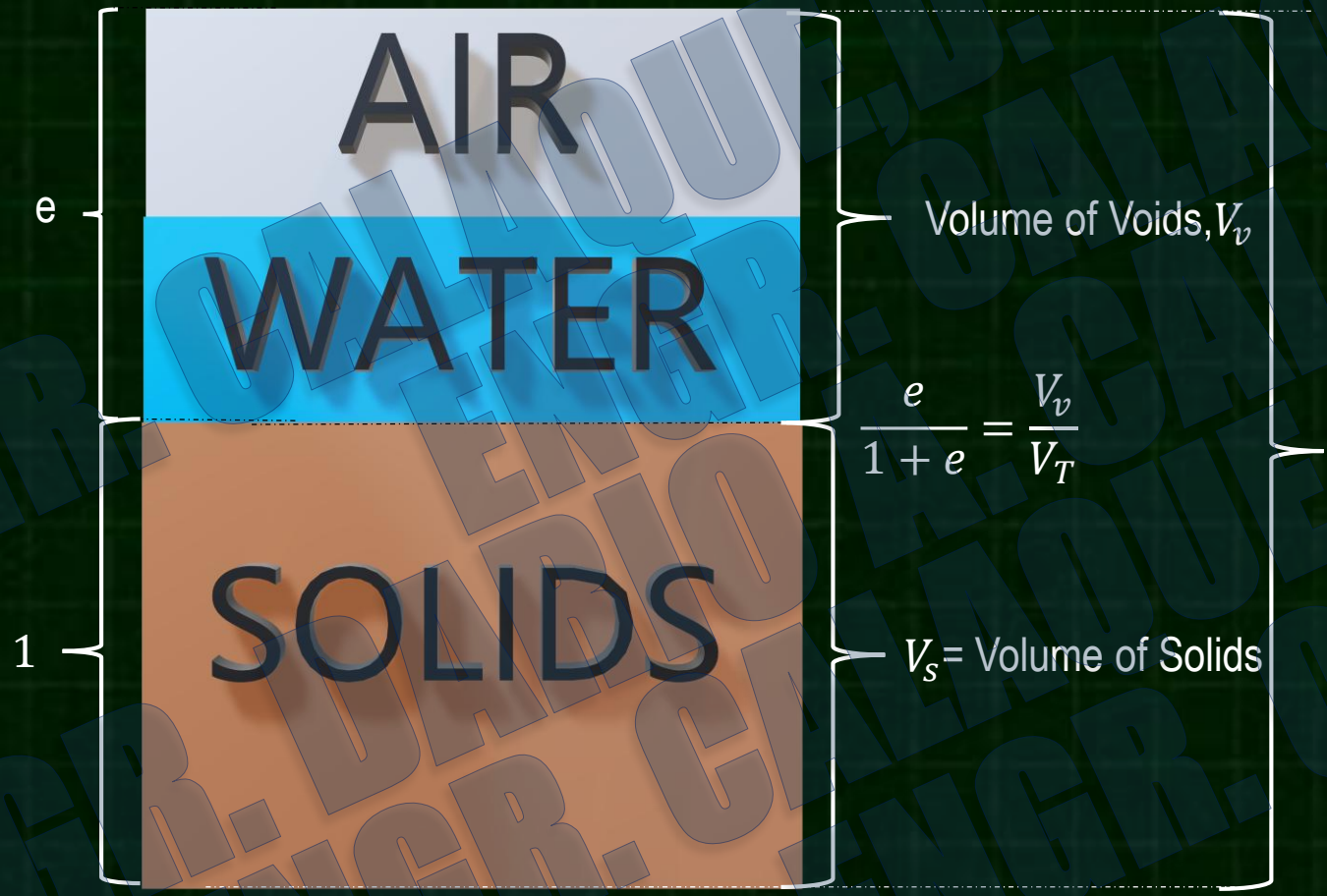

Porosity

$$n = \frac{V_v}{V_T}$$

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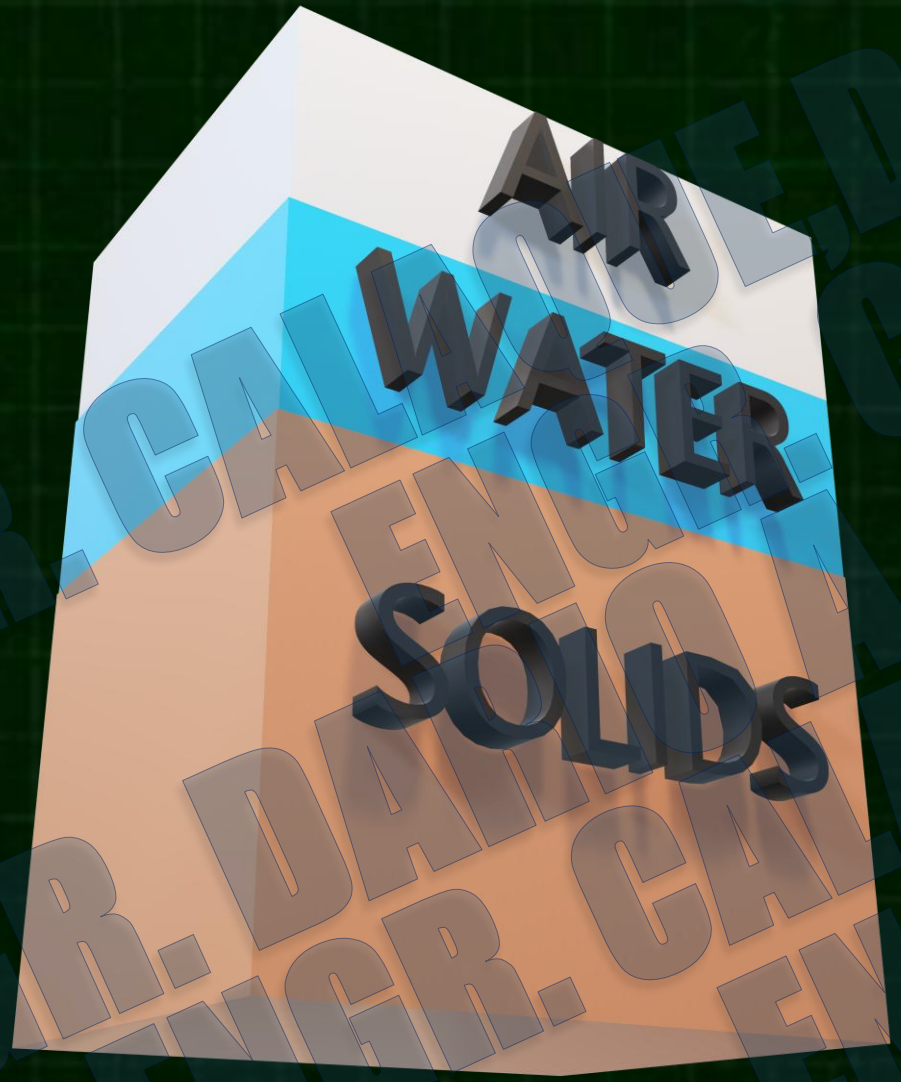
UNIT WEIGHT AND SPECIFIC GRAVITY



UNIT WEIGHT

$$\gamma = \frac{W}{V}$$

$$W = \gamma V$$

SPECIFIC GRAVITY

$$G_s = \frac{\gamma_s}{\gamma_w}$$

$$\gamma_s = G_s \gamma_w$$

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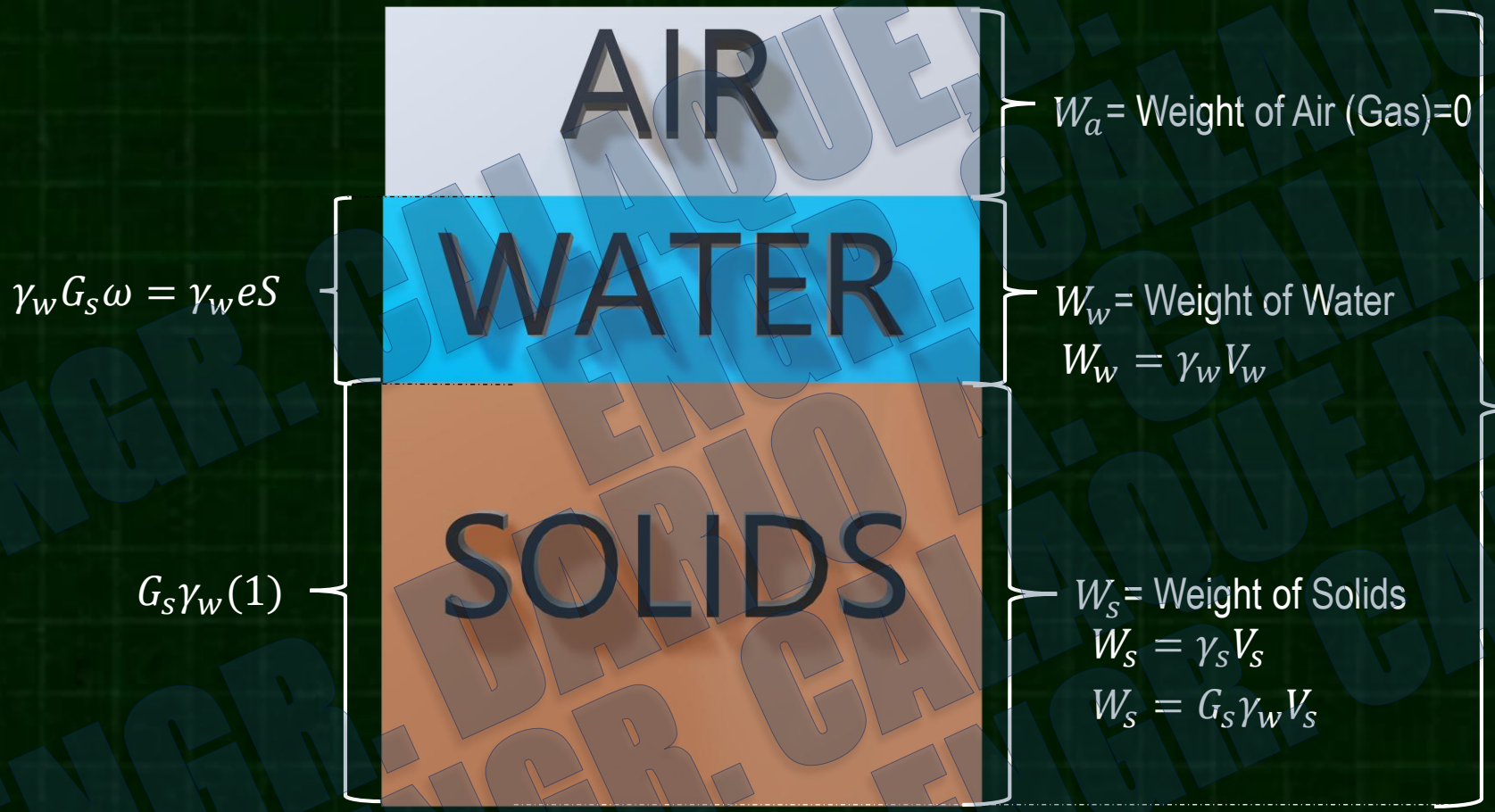

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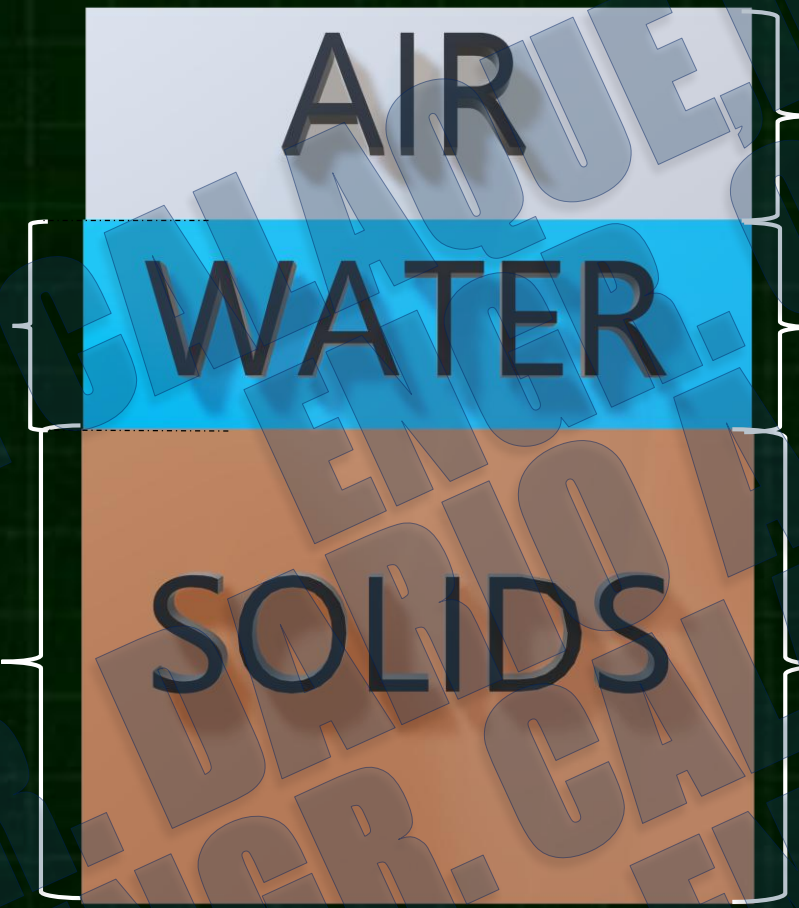

$\gamma_w G_s \omega = \gamma_w eS$

$G_s \gamma_w (1)$

W_a = Weight of Air (Gas)=0

W_w = Weight of Water

$W_w = \gamma_w V_w$

W_s = Weight of Solids

$W_s = \gamma_s V_s$

$W_s = G_s \gamma_w V_s$

Moisture Content

$$\frac{\gamma_w G_s \omega}{G_s \gamma_w (1)} = \frac{W_w}{W_s}$$

$$\omega = \frac{W_w}{W_s}$$

On dry weight basis

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UNIT WEIGHT OF SOIL

BULK/MOIST/TOTAL /WET UNIT WEIGHT

0% < S < 100%

$$\gamma_{moist} = \frac{W_T}{V_T}$$

$$\gamma_{moist} = \frac{\gamma_w(G_s + eS)}{1+e}$$

$$\gamma_{moist} = \frac{G_s\gamma_w(1+\omega)}{1+e}$$

SATURATED UNIT WEIGHT

S=100% = 1

$$\gamma_{sat} = \frac{W_{sat}}{V_T}$$

$$\gamma_{sat} = \frac{\gamma_w(G_s + e)}{1+e}$$

DRY UNIT WEIGHT

S=0% = 0

$$\gamma_{dry} = \frac{W_s}{V_T}$$

$$\gamma_{dry} = \frac{G_s\gamma_w}{1+e}$$

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PAST CE BOARD EXAM

In natural state, a moist soil sample has a volume of 0.33 ft^3 and weighs 39.93lbs. The oven dry weight of soils is 34.54lbs. If the specific gravity of a solid soil is 2.71

Calculate the following:

a) Moisture content
b) Moist unit weight
c) Dry unit weight
d) Void ratio
e) Porosity
f) Volume of Voids
g) Volume of solids
h) Volume of water
i) Volume of air
j) Degree of saturation

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MOISTURE CONTENT (%)

$$\omega = \frac{W_W}{W_S}$$

$$\omega = \frac{W_T - W_S}{W_S} x100$$

$$\omega = \frac{39.93 - 34.54}{34.54} x100$$

$$\omega = 15.61\%$$

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MOIST UNIT WEIGHT

$$\gamma_{moist} = \frac{W_T}{V_T}$$

$$\gamma_{moist} = \frac{39.93lbs}{0.33ft^3}$$

$$\gamma_{moist} = 121pcf$$

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DRY UNIT WEIGHT

$$\gamma_{dry} = \frac{W_s}{V_T}$$

$$\gamma_{dry} = \frac{34.54lbs}{0.33ft^3}$$

$$\gamma_{dry} = 104.67pcf$$

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VOID RATIO

$$\gamma_{dry} = \frac{W_s}{V_T} = \frac{G_s \gamma_w}{1+e}$$

$$104.67pcf = \frac{2.71(62.4)}{1+e}$$

$$e = 0.6156$$

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POROSITY

$$n = \frac{e}{1+e} = \frac{V_v}{V_T}$$

$$n = \frac{0.6156}{1+0.6156}$$

$$n = 0.381$$

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VOLUME OF VOIDS

$$n = \frac{e}{1+e} = \frac{V_v}{V_T}$$

$$0.381 = \frac{V_v}{0.33}$$

$$V_v = 0.1257 ft^3$$

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VOLUME OF SOLIDS

$$\gamma_S = \gamma_w G_S = \frac{W_S}{V_S}$$

$$62.4(2.71) = \frac{34.54}{V_S}$$

$$V_S = 0.2042 ft^3$$

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VOLUME OF WATER

$$\gamma_w = \frac{W_w}{V_w}$$

$$V_w = \frac{W_w}{\gamma_w}$$

$$V_w = \frac{W_T - W_S}{\gamma_w}$$

$$V_w = \frac{39.93 - 34.54}{62.4}$$

$$V_w = 0.0864 \text{ft}^3$$

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j) Degree of saturation

VOLUME OF AIR

$$V_a = V_v - V_w$$

$$V_a = 0.1257 ft^3 - 0.0864 \text{ft}^3$$

$$V_a = 0.0393 \text{ft}^3$$

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DEGREE OF SATURATION

$$S = \frac{V_w}{V_v}$$

$$S = \frac{0.0864}{0.1257} x100$$

$$S = 68.74\%$$

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DEGREE OF SATURATION

$$G_s = 2.71$$

$$\omega = 15.61\%$$

$$e = 0.6156$$

$$S = ???$$

$$G_s\omega = eS$$

$$2.71(15.61\%) = 0.6156S$$

$$S = 0.6872$$

$$S = 68.72\%$$

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PAST CE BOARD EXAM

For a given silt soil,
Dry unit weight = 116 pcf
Saturated unit weight = 122 pcf
Compute the moist/bulk unit weight (pcf) if the degree of saturation is 20%.

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PAST CE BOARD EXAM

For a given silt soil,
Dry unit weight = 116 pcf
Saturated unit weight = 122 pcf
Compute the moist/bulk unit weight (pcf) if the degree of saturation is 20%.

VOID RATIO

$$\gamma_{sat} = \frac{\gamma_w(G_s + e)}{1 + e}$$

$$\gamma_{sat} = \frac{\gamma_w(G_s)}{1 + e} + \frac{\gamma_w(e)}{1 + e}$$

$$Note: \gamma_{dry} = \frac{G_s\gamma_w}{1 + e}$$

$$\gamma_{sat} = \gamma_{dry} + \frac{\gamma_w(e)}{1 + e}$$

$$122 = 116 + \frac{62.4(e)}{1 + e}$$

$$e = 0.1064$$

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PAST CE BOARD EXAM

For a given silt soil,
Dry unit weight = 116 pcf
Saturated unit weight = 122 pcf
Compute the moist/bulk unit weight (pcf) if the degree of saturation is 20%.

SPECIFIC GRAVITY

$$\gamma_{dry} = \frac{G_s \gamma_w}{1 + e}$$

$$116 = \frac{G_s(62.4)}{1 + 0.1064}$$

$$G_s = 2.0568$$

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PAST CE BOARD EXAM

For a given silt soil,
Dry unit weight = 116 pcf
Saturated unit weight = 122 pcf
Compute the moist/bulk unit weight (pcf) if the degree of saturation is 20%.

MOIST UNIT WEIGHT

$$\gamma_{moist} = \frac{\gamma_w(G_s + eS)}{1+e}$$

$$\gamma_{moist} = \frac{62.4(2.0568+0.20(0.1064))}{1+0.1064}$$

$$\gamma_{moist} = 117.2 \text{pcf}$$

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Soil

Test 1

Moist Unit Weight = 17.73KN/m^3

Deg. Of Saturation = 75%

Test 2

Moist Unit Weight = 16.64KN/m^3

Deg. Of Saturation = 50%

Req'd:

1) Dry Unit Weight of Soil
2) Saturated Unit Weight of Soil
3) Porosity of Soil

$$\gamma_m = \frac{G+Se}{1+e}\gamma_w$$

$$17.73 = \frac{G+0.75e}{1+e}(9.81)$$

$$\frac{17.73}{9.81} = \frac{G+0.75e}{1+e}$$

$$G = \frac{17.73}{9.81}(1+e) - 0.75e \quad \cdots (1)$$

$$G = \frac{16.64}{9.81}(1+e) - 0.50e \quad \cdots (2)$$

(1) = (2) $\therefore e = 0.80$

$$n = \frac{e}{1+e} = 0.444$$

(2) $G = 2.653 \rightarrow (A)$

$$\gamma_{dry} = \frac{G}{1+e}$$

$= 14.46 \frac{KN}{m^3}$

$\gamma_{sat} = 18.82$

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TEST YOURSELF

For a given soil:

Dry unit weight = 110KN/m^3

Saturated unit weight = 160KN/m^3

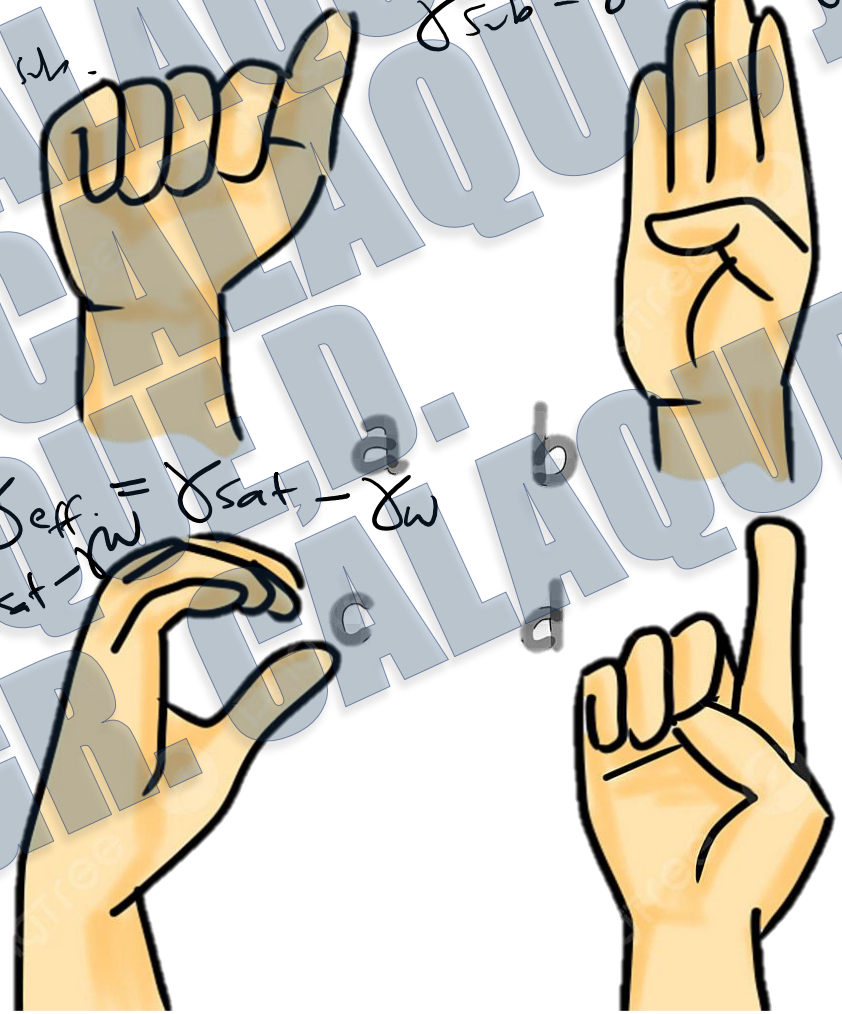
1. Determine the moist unit weight if 40% saturated.

a) 130KN/m^3

b) 120KN/m^3

c) 160KN/m^3

d) 140KN/m^3



CLASS PARTICIPATION:

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TEST YOURSELF

For a given soil:

Dry unit weight = 110KN/m^3

Saturated unit weight = 160KN/m^3

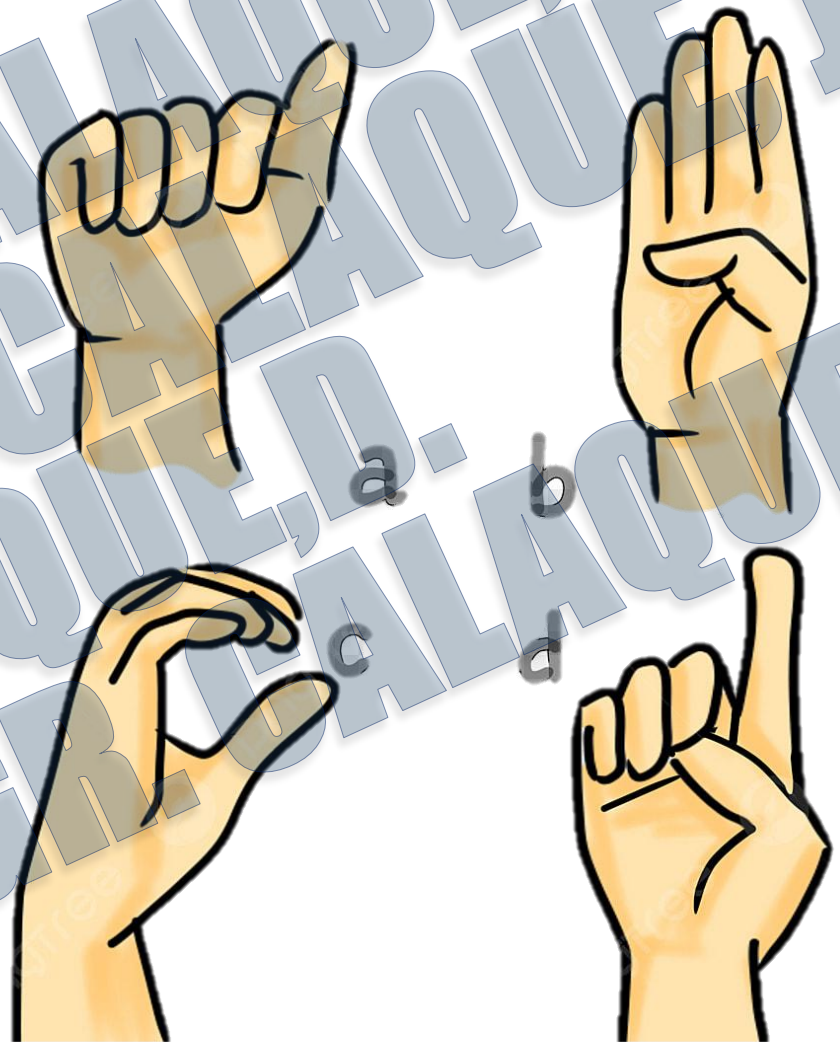
Determine the degree of saturation if the unit weight of soil is 125KN/m^3

a) 15%

b) 20%

c) 25%

d) 30%



CLASS PARTICIPATION:

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LET'S REVIEW

RELATIVE DENSITY

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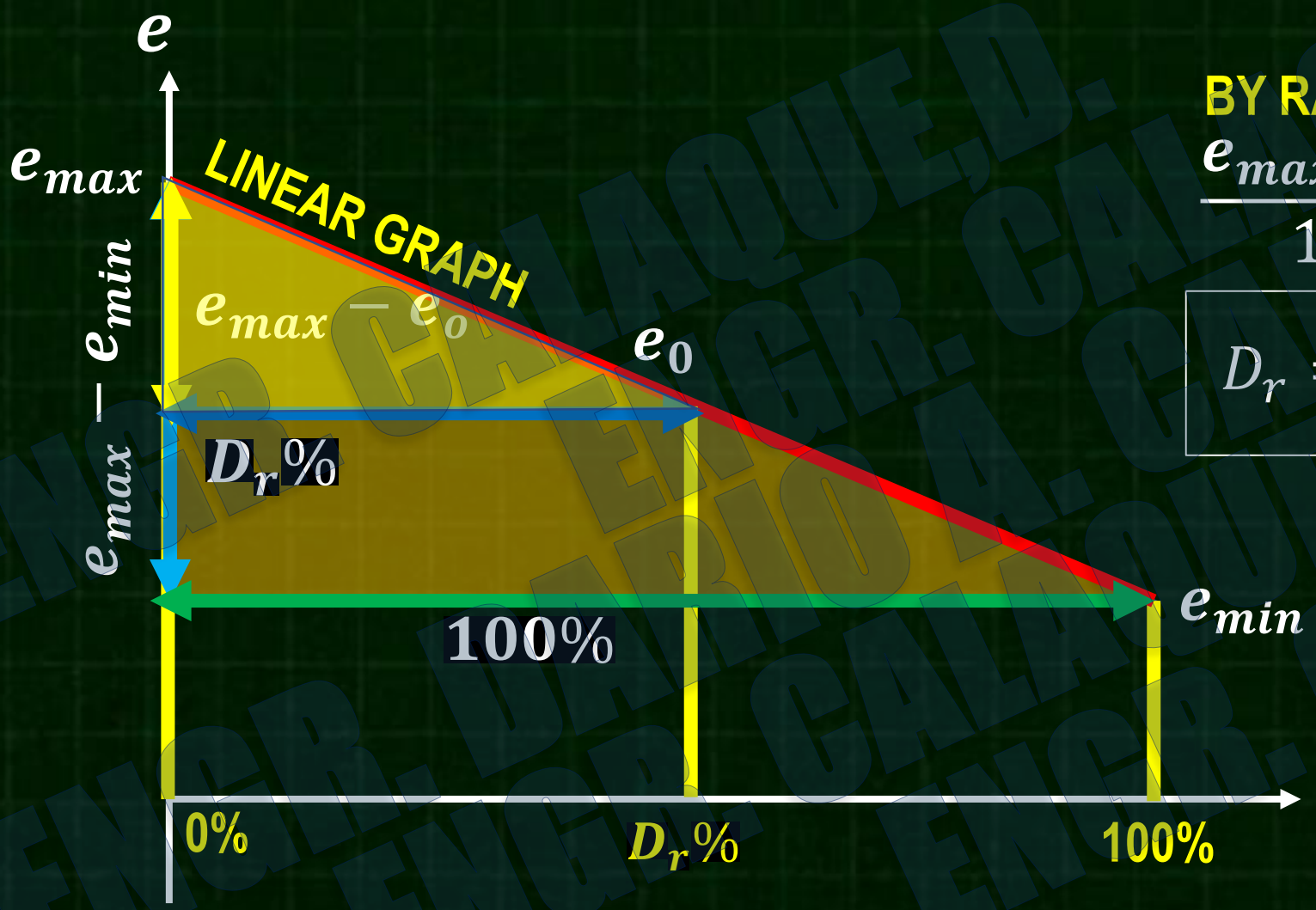
RELATIVE DENSITY



BY RATIO AND PROPORTION:

$$\frac{e_{max} - e_{min}}{100\%} = \frac{e_{max} - e_o}{D_r\%}$$

$$D_r = \frac{e_{max} - e_o}{e_{max} - e_{min}} x100\%$$

LOOSEST CONDITION MORE VOIDS

DENSEST CONDITION LESS VOIDS

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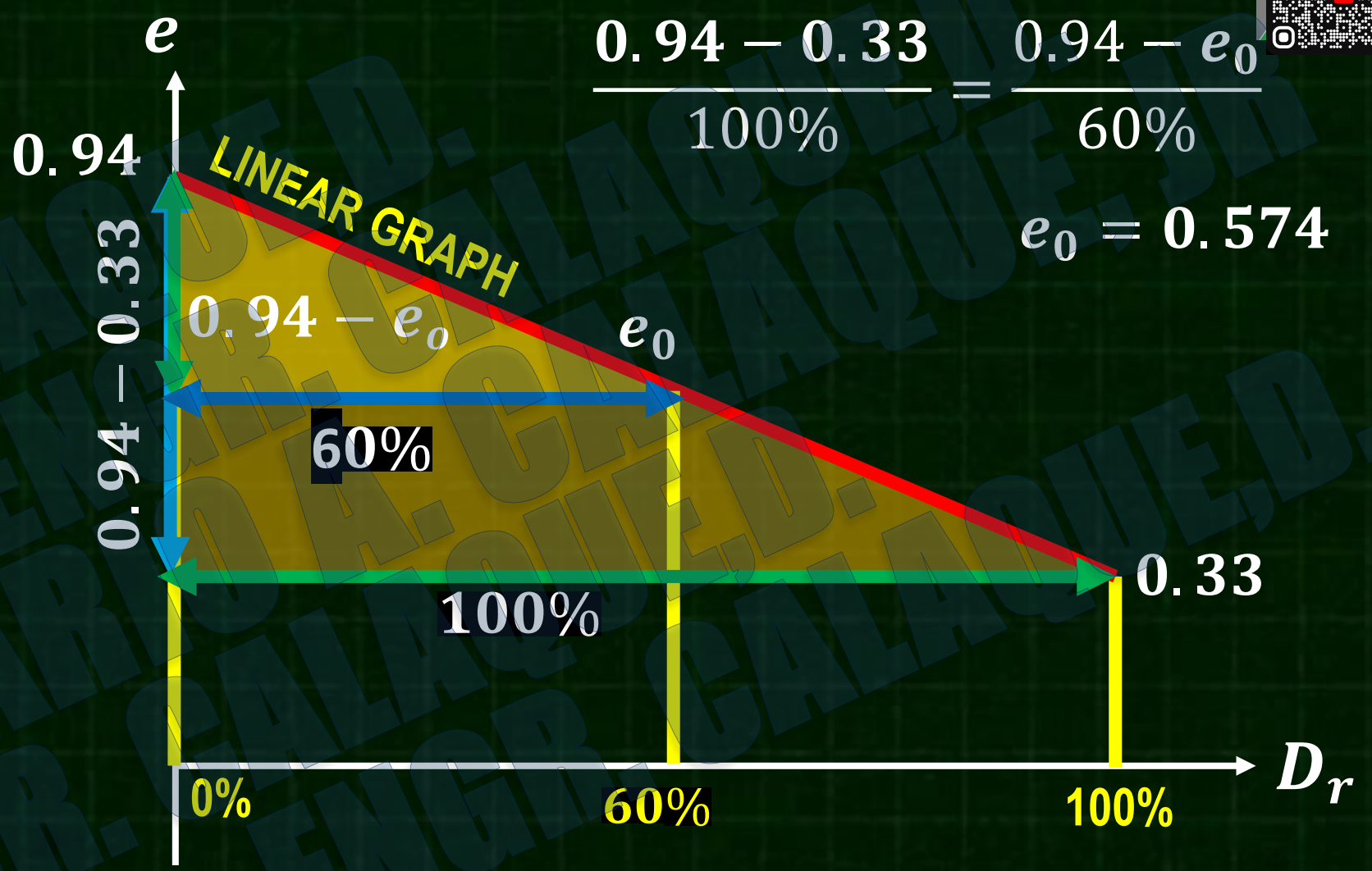
PAST CE BOARD EXAM:

For sand, the maximum and minimum void ratios were determined in the laboratory to be 0.94 and 0.33, respectively.

1. Find the moist unit weight of sand in KN/m^3 compacted in the field at a relative density of 60% and a moisture content of 10%. Gs = 2.65
2. Calculate the maximum and minimum dry unit weight in KN/m^3 that the sand can have.



BY RATIO AND PROPORTION:

$$\frac{0.94 - 0.33}{100\%} = \frac{0.94 - e_0}{60\%}$$

$$e_0 = 0.574$$

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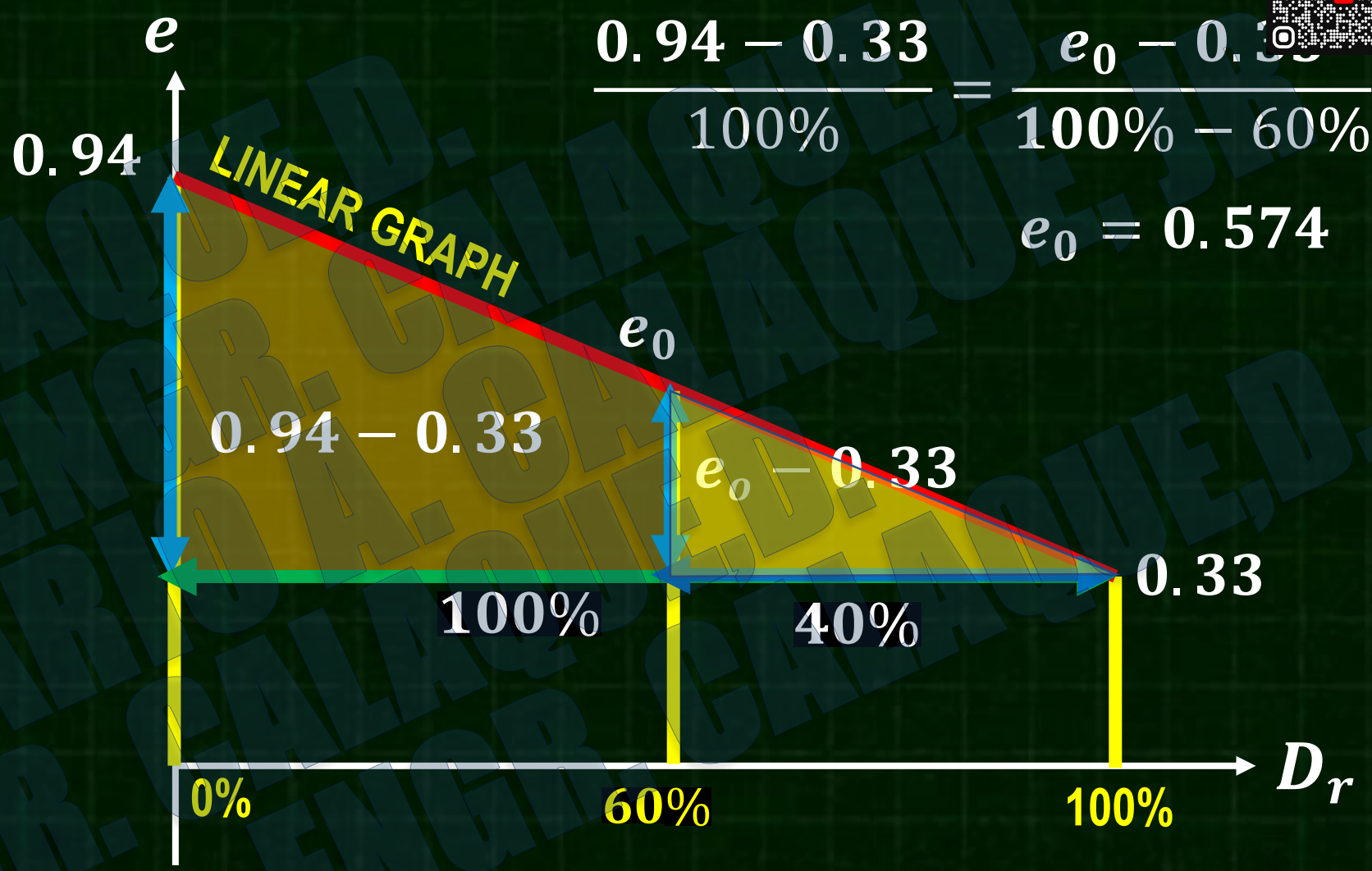

BY RATIO AND PROPORTION:

$$\frac{0.94 - 0.33}{100\%} = \frac{e_0 - 0.33}{100\% - 60\%}$$

$$e_0 = 0.574$$

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2. Calculate the maximum and minimum dry unit weight in KN/m^3 that the sand can have.

$$e_0 = 0.574$$

$$e_{max} = 0.94$$

$$e_{min} = 0.33$$

$$\gamma_{moist} = \frac{G_s \gamma_w (1+\omega)}{1+e}$$

$$\gamma_{moist} = \frac{2.65(9.81)(1+0.10)}{1+0.574}$$

$$\gamma_{moist} = 18.17 KN/m^3$$

$$\gamma_{dry} = \frac{G_s \gamma_w}{1+e}$$

$$\gamma_{dry\ max} = \frac{2.65(9.81)}{1+0.33}$$

$$\gamma_{dry\ max} = 19.55 KN/m^3$$

$$\gamma_{dry\ min} = \frac{2.65(9.81)}{1+0.94}$$

$$\gamma_{dry\ min} = 13.40 KN/m^3$$

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SOIL COMPACTION

GEOTECHNICAL ENGINEERING

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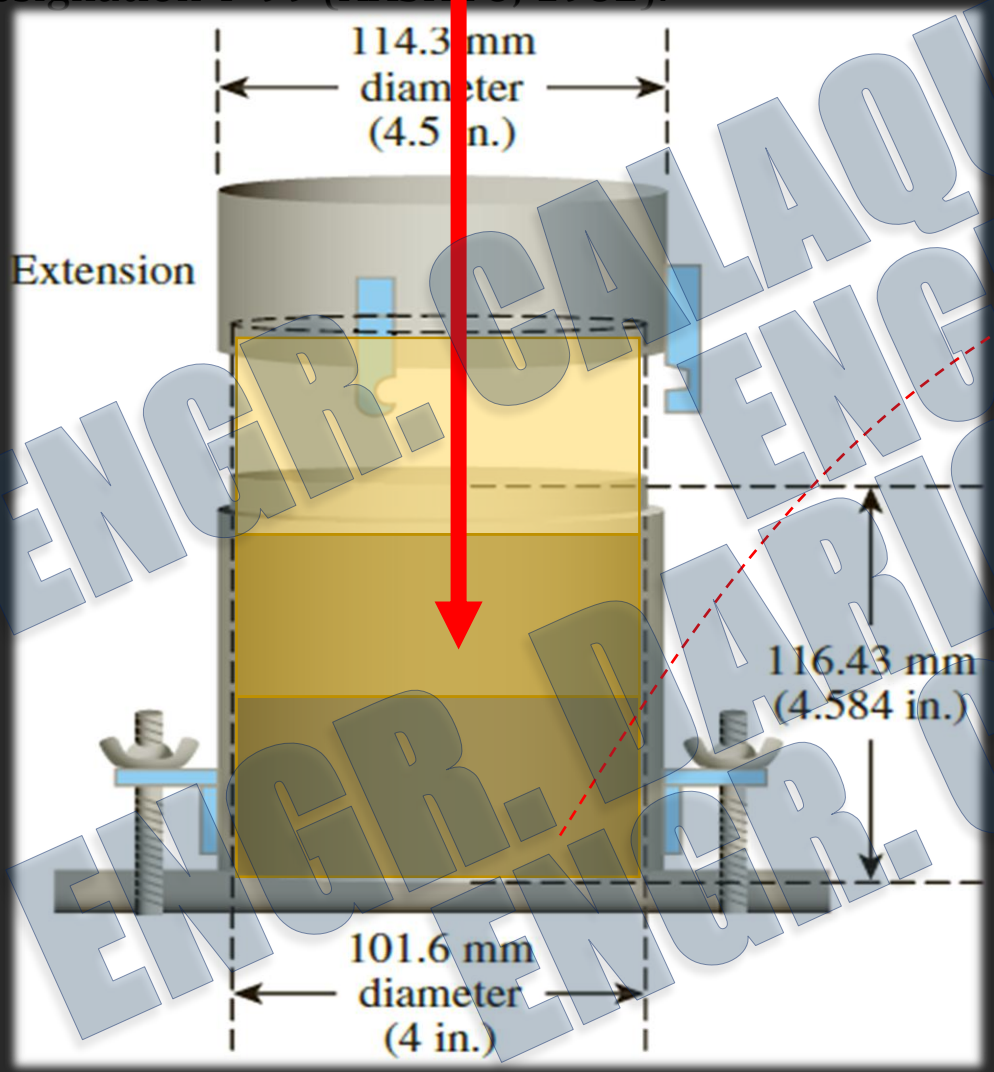
Standard Proctor Compaction

The procedure for the Standard Proctor test is elaborated in ASTM Test Designation D-698 (ASTM, 2014) and AASHTO Test Designation T-99 (AASHTO, 1982).



In the Proctor test, the soil is compacted in a mold that has a volume of 944 cm^3 $\left(\frac{1}{30}\ ft^3\right)$. The diameter of the mold is 101.6 mm (4 in.).

$$V = \frac{\pi}{4}\left(\frac{4}{12}\right)^2\left(\frac{4.584}{12}\right) = 0.0333 = \frac{1}{30} ft^3$$

During the laboratory test, the mold is attached to a baseplate at the bottom and to an extension at the top. The soil is mixed with water and then compacted in three equal layers by a hammer that delivers 25 blows to each layer.

The hammer has a mass of 2.5 kg (5.5 lb) and has a drop of 305 mm (12 in.).

For each test, the moist unit weight of compaction, , can be calculated as

$$\gamma_m = \frac{W}{V_m}$$

where W =weight of the compacted soil in the mold

V_m = volume of the mold [944 cm^3 $\left(\frac{1}{30}\ ft^3\right)$]

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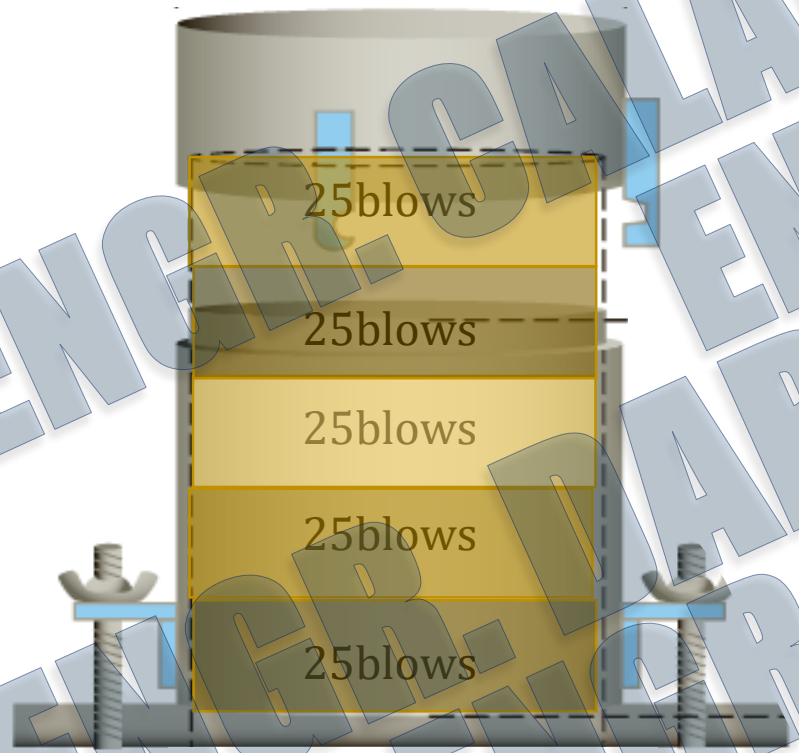
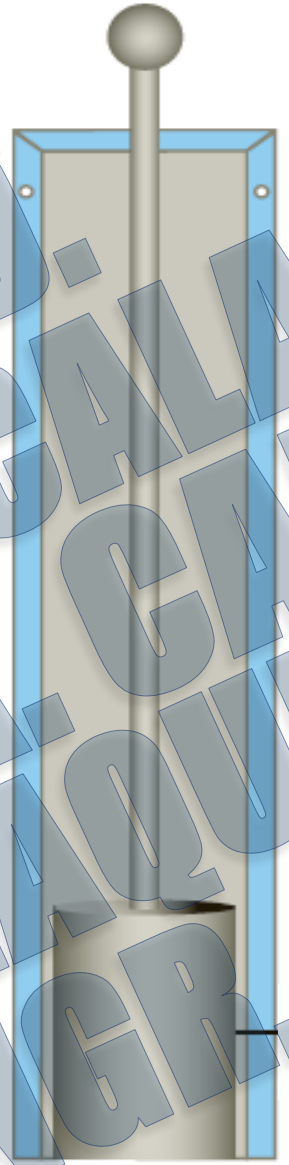
Modified Proctor Compaction

The procedure follows (ASTM Test Designation D-1557 and AASHTO Test Designation T-180).



Baseplate



For conducting the Modified Proctor the same mold is used with a volume $\text{cm}^3 \left(\frac{1}{30}\ \text{ft}^3\right)$.

$$V = \frac{\pi}{4}\left(\frac{4}{12}\right)^2\left(\frac{4.584}{12}\right) = 0.0333 = \frac{1}{30} ft^3$$

However, the soil is compacted in five layers by a hammer that has a mass of 4.54 kg (10 lb.). The drop of the hammer is 457 mm (18 in.). The number of hammer blows for each layer is kept at 25 as in the case of the standard Proctor test.

The compaction energy for this type of compaction test can be calculated as 2700 kN-m/m^3 (56,000 ft-lb/lb^3).

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- For each test, the moisture content of the compacted soil is determined in the laboratory. With the known moisture content, the dry unit weight can be calculated as:

$$\gamma_{dry} = \frac{\gamma_m}{1 + \omega}$$

where: $w(in\ dec.\ form)$ = percentage of moisture content

- The values of γ_d determined from the equation above can be plotted against the corresponding moisture contents to obtain the maximum dry unit weight and the optimum moisture content for the soil.

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PERCENT COMPACTION

OR RELATIVE COMPACTION

$$R = \frac{\gamma_{dry\ field}}{\gamma_{dry\ max.lab.}}$$

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PAST CE BOARD EXAM.

The volume of mold is 1/30 cubic ft. Given the weight of compacted moist soil in proctor mold corresponding to its water content as tabulated below:

Water Content	Wt. of comp. moist soil
10%	3.78 lbs.
12%	4.01 lbs.
14%	4.14 lbs
16%	4.12 lbs
18%	4.01 lbs
20%	3.90 lbs

Determine the following:

1. Max. Dry density unit weight of compaction
2. Optimum moisture content
3. Percent compaction in the field if the sample at the field has wet unit weight of 135 pcf, specific gravity of 2.65 and a moisture content of 11%.

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EX: The volume of mold is 1/30 cubic ft. Given the weight of compacted moist s proctor mold corresponding to its water content as tabulated below:

Water Content	Wt.of comp.moist soil
10%	3.78 lbs.
12%	4.01 lbs.
14%	4.14 lbs
16%	4.12 lbs
18%	4.01 lbs
20%	3.90 lbs

Solution:

$$\gamma_{dry} = \frac{\gamma_m}{1+\omega} = \frac{W_T}{V_T(1+\omega)}$$

$$\gamma_{dry} = \frac{3.78}{(1/30)(1+0.10)} = 103.1\ pcf$$

$$\gamma_{dry} = \frac{4.01}{(1/30)(1+0.12)} = 107.4\ pcf$$

$$\gamma_{dry} = \frac{4.14}{(1/30)(1+0.14)} = 108.9\ pcf$$

$$\gamma_{dry} = \frac{4.12}{(1/30)(1+0.16)} = 106.6pcf$$

$$\gamma_{dry} = \frac{4.01}{(1/30)(1+0.18)} = 101.9pcf$$

$$\gamma_{dry} = \frac{3.90}{(1/30)(1+0.20)} = 97.5pcf$$

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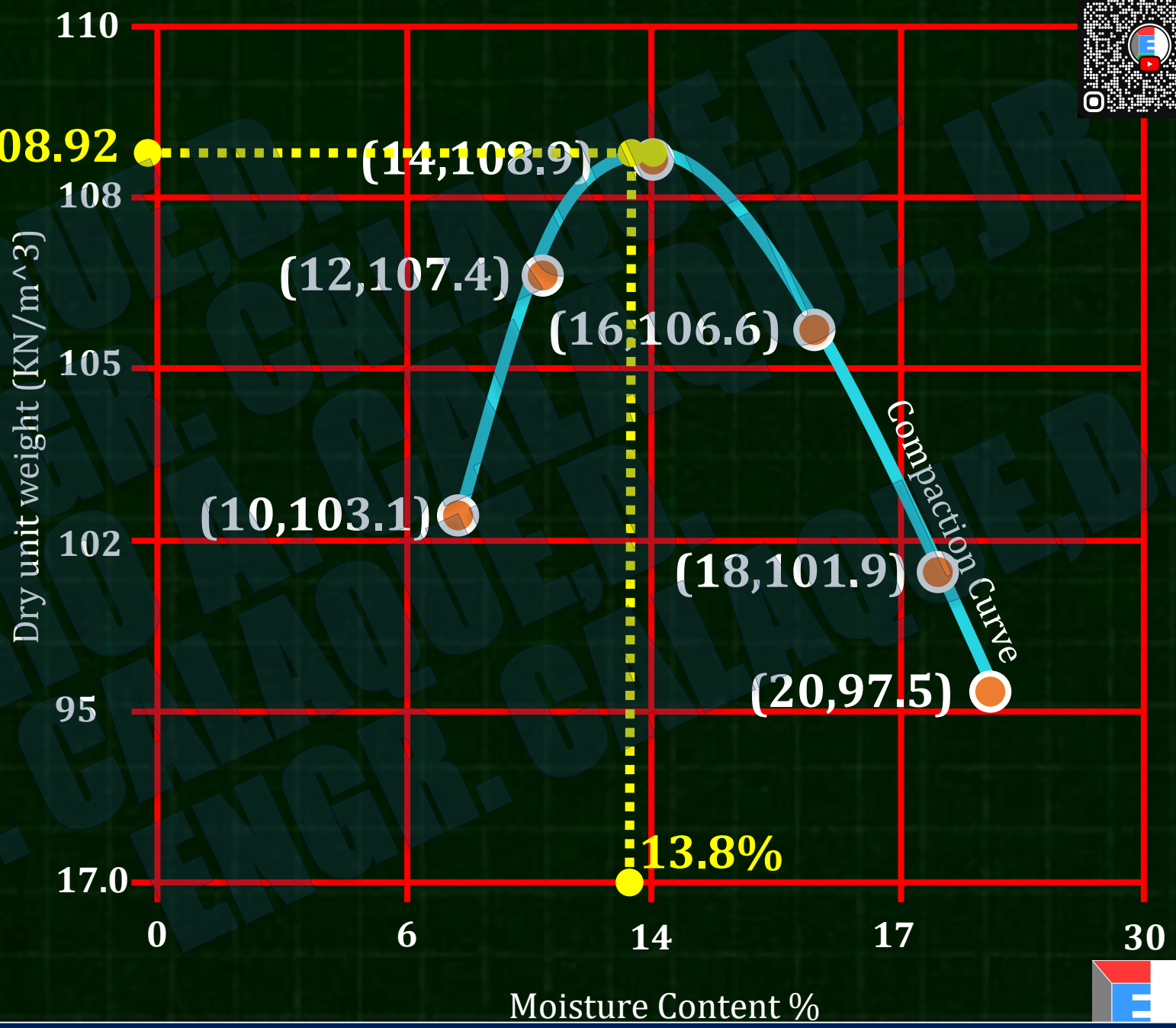
Plot γ_d $vs.$ w



From the graph,

Optimum moisture content
= **13.8%**

Maximum dry unit weight
= **108.92pcf**

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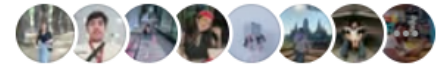

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